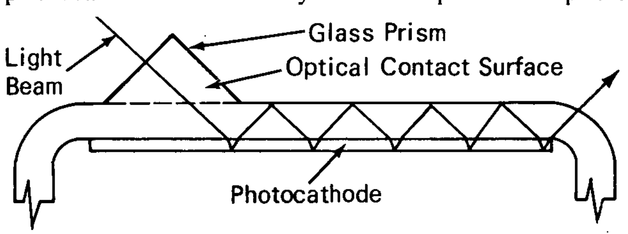
NASA TECH BRIEF

Ames Research Center

Optical Enhancement of Photomultiplier Sensitivity

The problem:

Increase the sensitivities of commercially available photocathode devices to values approaching the theoretical limit for visible light. Semitransparent photocathodes commonly used in photomultipliers



sensitive to visible light (S-11, S-20, etc.) do not absorb all the incident light. At a wavelength of 400 nm, a typical S-20 photocathode will reflect 40%, transmit 10%, and absorb only 50% of the light; at 700 nm, the same photocathode will reflect 30% transmit 50%, and absorb only 20%.

The solution:

Reduce light losses due to transmission and reflection by introducing light into the end-window of the device at an angle large enough to the normal so that total internal reflection occurs at both the photocathode-vacuum and window-air interfaces.

How it's done:

Immersion oil or optical cement is used to optically couple a small $\pi/4-\pi/2-\pi/4$ rad (45°–90°–45°) glass prism to the plano-plano end window of a photomultiplier. The multiple reflections resulting cause the photocathode to absorb more of the light, thus increasing photomultiplier sensitivity by a factor of 1.5 to 5, depending on wavelength.

The refractive index of the photocathode need not be known to determine the angle within the end window for total reflection. In layered media,

$$n_1\sin\Theta_1 = n_2\sin\Theta_2 = \ldots n_j\sin\Theta_j = \text{a constant, } k$$

Light traveling in the layered media will be totally reflected whenever it encounters a layer with an index of $n<k$. Since the refractive indices of air and vacuum are both approximately 1.0, the condition for total reflection at the air-window interface and the cathode-vacuum interface are the same, namely, $\sin\Theta_2 > (1/n_2)$ in the end window. Although little light is lost as a result of scattering at the two surfaces, a dark-adapted observer can see where the light is bouncing on the cathode and the external surface of the window by viewing the small amount of forward scattered light. This can be useful in making adjustments.

Factors to be considered in designing optical enhancement devices include the area and acceptance angle required, the wavelengths of interest, and the thickness and optical index of the photomultiplier window. These factors interact with each other and with other design parameters such as the optical index of the entrance optics. For example, with the simple glass prism shown in the figure, the acceptance cone is limited to f/6; however, with a prism of high-index glass, speeds of f/2 and faster can be attained. Sapphire may be employed for small devices, especially those designed for photomultiplier tubes having windows transparent to UV radiation. Special entrance optics can be adapted for systems involving physical constraints which prevent the use of simple prisms.

(continued overleaf)

References:

1. Gunter, W. D., Jr.; Grant, G. R.; and Shaw, S. A.: Optical Devices to Increase Photocathode Efficiency. Applied Optics, vol. 9, p. 251, February 1970.
2. Jennings, R. J.; Gunter, W. D., Jr.; and Grant, G. R.: Quantum Efficiencies Greater than 50% from Commercially Available Photomultipliers. Journal of Applied Physics, vol. 41, No. 5, p. 2266-2267, April 1970.

Notes:

1. The combination of field-enhanced gain with the optical gain described provides even greater sensitivity in the near-infrared region. (See W. D. Gunter, Jr., R. J. Jennings, and G. R. Grant, "Dual Enhancement of Photocathode Sensitivity in the Near Infrared," Applied Optics, vol. 7, p. 2143, October 1968.)
2. A 14 1/2-minute sound, color film entitled "Optical Enhancement of Photomultiplier Tubes—A Method of Obtaining Large Increases in the Quantum Efficiency of Photocathodes" is available for loan. Requests for loan should be directed to the Technology Utilization Officer at Ames Research Center.
3. Requests for further information may be directed to:

   Technology Utilization Officer
   Ames Research Center
   Moffett Field, California 94035
   Reference: B71-10113

Patent status:

No patent action is contemplated by NASA.

Source: W. D. Gunter, Jr. and G. R. Grant
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